Adaptive Behavior

Commentary

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Response to Fred Keijzer's comments

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First, I appreciate the critical appraisal of my paper by Fred Keijzer (2019), which further stimulates and helps crystalize my thoughts on immunity and cognition. My paper was developed from the search for the essence of immunity by studying immune functions in bacteria (Yakura, 2018). From this search, I learned two lessons. The first is that the definition of the immune system is based on its functional, but not structural, makeup. I thought that the same principle should be applied to the definition of cognitive systems. The second lesson is that the minimal functional components of the immune system in bacteria, namely, sensing of signals in milieu, integration of perceived information, a reaction based on integrated information, and the memory of that experience, are conserved throughout the evolution of immunity and almost completely superimpose upon the functional components of the central nervous system. This suggests that the immune system may serve as a neural-like functional machinery in bacteria, presumably in the absence of the nervous system.

As I read Keijzer's comments, I came to realize that I unconsciously considered the problem of minimal cognition in terms of finding a process involving cognitive activities that fulfills the above criteria in an organism at the earliest evolutionary stage. Thus, my conclusion was that the perfect case for minimal cognition was the immune system of bacteria. For this reason, I thought that the bacterial immune system was "a more universal and fundamental cognitive system in living beings." This conclusion also evades critiques of neo-Darwinism, the paradigm of modern biology (Nagel, 2012), because, as a highly significant condition, adversaries of neo-Darwinism demand that cognitive (or mental) mechanisms be preceded by other organisms in the earlier stages of evolution. If one takes this demand seriously, it is obligatory to adopt criteria such as my conclusion.

Concerning the first point raised by Keijzer, he is right to note that this study provides a new example, but not a criterion. However, this should be interpreted in terms of the above reasoning. Given the functional components proposed for minimal cognition (Lyon, 2015), the immune system of bacteria may serve as a better example, rather than chemotaxis or other molecular regulatory networks in the cell, for the reasons discussed in the paper (Yakura, 2018). As for the second and third points, it is important to remember that although the bacterial immune system is of a biochemical and genetic nature, what counts most is not the structural features of a candidate system but the functional characteristics that it produces. Needless to say, any functional system has its proper structural basis, but our proposal does not demand that a minimal cognitive system should have structures similar or identical to CRISPR-Cas. Thus, I do not think this contradicts our own conclusion. At the same time, I completely agree with Keijzer's points that this is not the final answer for minimal cognition, that there is always a possibility of finding a system with more appropriate and broader explicative powers in the future, and that we must never forget to study real systems to understand cognitive phenomena.

Finally, the fact that immune phenomena are found in almost all living beings suggests that (1) life and immunity have been intricately interwoven throughout life history; (2) similar to immunity, a cognitive system with memory is required for the existence and survival of life; and (3) the immune system, as a cognitive apparatus, has the broadest distribution in the realm of living organisms. In other words, immunity is coextensive with life such that if a possible extraterrestrial life form is found, the presence of an immune system, judged by functional, but not structural, conditions of cognition, may become a determining factor to confirm its authenticity. Anne Marie Moulin (1991) indicates that

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immunology is composed of three paradigms, namely, defensive, selective, and cognitive. Although the defensive and selective aspects of immunity are well established, the finding that immunity is present in bacteria in the form of cognitive as well as defensive activities stresses the importance of the cognitive paradigm in immune function (Cohen, 1992a, 1992b). The finding also implies that the immune system constitutes a more inclusive neural-like cognitive apparatus in living organisms than the nervous system, particularly in the earliest forms of life during evolution. The universality of immunity as a cognitive function may change our perspectives on one of the most fundamental activities of life (in preparation).

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